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EECS 280 Final Exam
Fall 2017

This is a closed-book exam. You may use one note sheet, 8.5”x11”, double-sided, with your name on it. This exam has 5 problems on 16 pages, and it is out of 80 points total. In addition to this exam booklet, you are also provided a reference packet with scratch space.

Read the entire exam through before you begin working. Work on those problems you find easiest first. Read each question carefully, and note all that is required of you. Keep your answers clear and concise, and state all of your assumptions carefully. Write your answers in the space provided. Assume all code is in standard C++11, and use only standard C++11 in your solutions.

Write your uniqname on the line provided at the top of each page.

You are to abide by the University of Michigan/Engineering honor code. To receive a grade, sign below to signify that you have kept the honor code pledge:

I have neither given nor received aid on this exam, nor have I concealed any violations of the Honor Code.

Signature: Solutions _____

Name: _____

Uniqname: _____

UMID: _____

Exam Room Number: _____

First and last name of person sitting to your **right** (write the symbol ⊥ if at the end of a row):

_____

First and last name of person sitting to your **left** (write the symbol ⊥ if at the end of a row):

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Correctly completing this cover page is worth **1 point**.

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Problem 1: Short Answer (19 Points)

1a) (6 points) For each of the following, fill in the bubble next to **True** or **False**. (Make sure to erase completely if you change your answer.)

i) The Rule of the Big Three states that if a class has member variables that are pointers, it must implement custom versions of the copy constructor, assignment operator, and destructor.

○ True ● False

Counterexample: List<T>::Iterator

ii) It is legal for a pointer whose type is `int *` to contain the address of an `int` object on the stack.

● True ○ False

example: passing a local array to a function

iii) If class `A` contains a declaration of the form `friend class B;`, then the code in class `A` can access the private members of class `B`.

○ True ● False

It gives B access to A, not the other way around.

iv) A try block cannot have more than one catch block that is associated with it.

○ True ● False

v) If a recursive call is on the last line of a function, then the function is always tail recursive.

○ True ● False

counterexample: non-tail-recursive factorial()

vi) A person suffering from impostor syndrome does not recognize their own accomplishments and believes they do not truly belong in the field in which they work.

● True ○ False

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1b) (6 points) Consider the following class definition.

```
class RobotArm {
public:
  RobotArm() : num_joints(0) {}
  void add_joint(const std::string &name) {
    joints[num_joints] = new Joint { name };
    ++num_joints;
  }
  void remove_joint() {
    if (num_joints > 0) {
      --num_joints;
      delete joints[num_joints];
    }
  }
private:
  struct Joint {
    std::string name;
  };
  Joint * joints[10];
  int num_joints;
};
```

For each of the lines of code below, determine if memory is leaked when the lines execute.

Memory leak when the lines below execute?	Yes	No
`int main() { // program starts`	○	●
`  RobotArm *ra = new RobotArm;`	○	●
`  ra->add_joint("wrist");` `  ra->add_joint("elbow");`	○	●
`  ra->remove_joint();`	○	●
`  delete ra;` This is what causes the program to lose track of the "wrist" joint.	●	○

`  return 0;  // program exits`
`}`
	○	●

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1c) (4 points) Consider the following function template and class definition.

```
template <typename T>
bool less_than(T x, T y) {
  return x < y;
}
```

```
class Duck {
  std::string name;
public:
  Duck(std::string name_in)
    : name(name_in) {}
};
```

What is the result of each call to `less_than()` below? If the code does not compile, select "Compile Error". If execution of the statement crashes when it is run, select "Runtime Error". If the code compiles and the call to `less_than()` returns true, select "True", and if it returns false, select "False".

Call to `less()`	Compile Error	Runtime Error	True	False
`less_than(5, 10);`	○	○	●	○

`std::string s1 = "hello";`
`std::string s2 = "world";`
`less_than(s1, s2);`
	○	○	●	○

`Duck duck1("Huey");`
`Duck duck2("Dewey");`
`less_than(duck1, duck2);`
no operator on Ducks
	●	○	○	○

`Duck ducks[1] = { Duck("Louie") };`
`less_than(ducks, ducks + 1);`
compares pointers
	○	○	●	○

1d) (3 points) Consider the following program.

```
#include <iostream>
class Exception {};
class DivisionException {};
class NotImplementedException {};

double reciprocal(int x) {
  if (x == 0) { throw DivisionException(); }
  return 1.0 / x;
}

double read_and_reciprocate() {
  int input;
  try {
    if (std::cin >> input) {
      return reciprocal(input);
    } else {
      throw Exception();
    }
  } catch (NotImplementedException &e) {
    std::cout << "Not implemented" << std::endl;
    return 0;
  }
}

int main() {
  try {
    std::cout << read_and_reciprocate() << std::endl;
    std::cout << read_and_reciprocate() << std::endl;
  } catch (DivisionException &e) {
    std::cout << "Bad division" << std::endl;
  }
}
```

For each of the following inputs on standard input, what does the program print? If nothing is printed, write "nothing". If the program crashes when it is run, write the output that is printed before it crashes, as well as "runtime error".

Input	Output
2	0.5 runtime error The second extraction fails, so the code throws an Exception. This doesn't match an active catch block, so the program crashes.
2 10	0.5 0.1
0 1	Bad division Execution proceeds past the try/catch when the DivisionException is caught, so the second read-and-reciprocate() is skipped.

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Problem 2: Dynamic Memory (16 Points)

Consult the separate **Problem 2 Reference Sheet** for this problem.

2a) (5 points) Implement the `Cinema::add_movie` function according to the RME. Your implementation **MUST NOT** leak any memory.

```
// REQUIRES: num_movies <= MAX_MOVIES
// MODIFIES: *this
// EFFECTS: Creates a new movie with the given title and length,
//          and adds the new movie to the end of the movies array.
//          If the array is already full, then the last item will
//          be removed and replaced by the new one.
void Cinema::add_movie(const string& title, int length) {
```

```
  if (num_movies == MAX_MOVIES) {
    delete movies[--num_movies];
  }
  movies[num_movies++] = new Movie(title,
                                   length);

  // OR
  if (num_movies == MAX_MOVIES) {
    *movies[num_movies-1] = Movie(title, length);
  } else {
    movies[num_movies++] = new Movie(title,
                                     length);
  }
```

```
}
```

2b) (7 points) Implement a copy constructor for Cinema. It should make a deep copy of all the movies in the array and **MUST** use the `add_movie` function from above. Write it as it would appear **outside** the class definition.

```
Cinema::Cinema(const Cinema &other)
  : name(other.name), num_movies(0)
  /* alternatively can delegate:
     Cinema(other.name)  */  {
    for(int i=0; i<other.num_movies; ++i){
      add_movie(other.movies[i]->get_title(),
                other.movies[i]->get_length());
    }
}
```

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2c) (4 points) Which of the following ***must*** be defined to make the following code work successfully (compile and have no memory errors or leaks)? Assume the relevant libraries, header files, and `using` declarations are included. Fill in the bubble for Yes or No below for each item. (Make sure to erase completely if you change your answer.)

```
int main() {
    Cinema Rave_Cinemas("Rave");
    Rave_Cinemas.add_movie("Justice League", 119);
    Rave_Cinemas.add_movie("Star Wars: The Last Jedi", 150);

    Cinema Quality_16(Rave_Cinemas);
    Cinema Michigan_theater = Quality_16;

    Movie old_movie("Guess who's coming to dinner", 120);
    Quality_16.add_movie(old_movie);

    cout << old_movie.get_title() << endl;
    cout << Quality_16 << endl;

    return 0;
}
```

Both call the copy constructor, since they initialize a new object.

Must be defined to avoid errors in the code above?	Yes	No
A default constructor for **`Cinema`**	○	●
An overloaded assignment operator for **`Movie`**	○	●
An overloaded assignment operator for **`Cinema`** Not used in the code above	○	●
An overloaded **`add_movie`** function that takes in a **`Movie`**	●	○
A destructor for **`Movie`** Does not manage dynamic memory	○	●
A destructor for **`Cinema`**	●	○
An overloaded **`operator<<`** for **`Movie`**	○	●
An overloaded **`operator<<`** for **`Cinema`**	●	○

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Problem 3: Lists and Templates (14 Points)

Consider the following class template:

```
template <typename T>
class List {
public:
  // EFFECTS: Initializes this list to be empty.
  List() : first(nullptr), last(nullptr) {}

  // YOU WILL WRITE THIS IN 3b)
  void truncate(const T &item);

  // Assume the big three are defined as needed.
private:
  struct Node {
    T datum;     // the element stored in this Node
    Node *next; // the next Node, or null if there is none
    Node *prev; // the previous Node, or null if there is none
  };
  Node *first;  // the first Node in the list, or null if it is empty
  Node *last;   // the last Node in the list, or null if it is empty

  // YOU WILL WRITE THIS IN 3a)
  Node * find(const T &item);
};
```

For 3a) and 3b), you may **NOT** use any functions that do not appear in the class declaration above. Your functions **MUST** be iterative, and you may **NOT** use recursion. Your code must **NOT** leak any memory. You **MAY** assume that the type `T` supports the `==` and `!=` operators.

3a) (4 points) Implement `find()` according to its RME.

```
// EFFECTS: Returns a pointer to the first node that contains 'item',
//          or nullptr if 'item' is not in the list.
Node * find(const T &item) {
```

```
Node * node = first;
for (; node and node->datum != item;
      node = node->next);
return node;
// OR
for (Node * node = first; node; node = node->next) {
  if (node->datum == item) { return node; }
}
return nullptr;
```

```
}
```

3b) (10 points) Implement `truncate()` according to its RME. You **MUST** use `find()`, and you may assume it is implemented correctly.

```
// MODIFIES: *this
// EFFECTS: If 'item' is in the list, removes the first appearance of
//          'item' and all elements that follow from the list.
// EXAMPLE: If 'list' contains [2, 3, 1, 4, 1], then list.truncate(1)
//          modifies 'list' to contain [2, 3].
//          If 'list' contains [2, 3, 1, 4, 1], then list.truncate(5)
//          does not change 'list'.
void truncate(const T &item) {
```

```
  Node *node = find(item);
  if (node) {
    last = node->prev;
    if (last) {
      last->next = nullptr;
    } else {
      first = nullptr;
    }
    // alternatively: (last? last->next: first) = nullptr;
    while (node) {
      Node *victim = node;  // necessary to move
      node = node->next;    // pointer before deleting
      delete victim;        // to avoid using zombie object
    }
  }
  // can also implement this by working backward
}
// from last until node, but a bit more complicated
```

Problem 4: Iterators and Functors (16 Points)

4a) (3 points) Consider an `IntRange` class that is created with `start` and `stop` int values, representing the integers in the range `start, start+1, ..., stop-1` (it includes `start` but not `stop`). It can then be used inside a *range-based for* loop to execute the loop body with an integer starting at `start` and increasing by one each time until reaching `stop`.

```
IntRange range(1, 5);
for (int i : range) {
  cout << i << " ";
} // will output "1 2 3 4 "
```

Here is the code for `IntRange`, which is missing the public interface for its `Iterator` nested class.

```
class IntRange {
public:
  IntRange(int start_in, int stop_in)
    : start(start_in), stop(stop_in) {}
  class Iterator {
    public:
      // Your public member functions here
    private:
      Iterator(int i_in) : i(i_in) {}
      int i;
      friend class IntRange;
  };
  Iterator begin() const { return Iterator(start); }
  Iterator end() const { return Iterator(stop); }
private:
  int start, stop;
};
```

Which `Iterator` member functions **MUST** you implement in order for the iterator to be used in the *range-based for* loop above?

Must be defined to be used above?	**Yes**	**No**
Overloaded **`!=`** operator for **`IntRange::Iterator`**	●	○
Overloaded prefix **`*`** operator for **`IntRange::Iterator`**	●	○
Custom implementations of the Big Three for **`IntRange::Iterator`**	○	●

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4b) (4 points) Write the following `filtered_copy` function, which copies items of type `T` from the given range into the provided `dest` vector if they satisfy the given `Predicate`. You may **NOT** use anything from the standard library other than vector member functions.

```
// REQUIRES: 'begin' and 'end' are valid iterators
//           'begin' is before or equal to 'end'
//           IterType fulfills the standard iterator interface
//           Predicate fulfills the standard predicate interface
// MODIFIES: the input vector 'dest'
// EFFECTS:  For each item from 'begin' to 'end',
//           appends that item to the given vector 'dest'
//           if Predicate 'pred' returns true for that item
// EXAMPLE:  begin and end define a sequence containing {1, 8, 3, 4}
//           and pred = IsEven, where IsEven(x) is true if x is even
//           Appends the items 8 and 4 to an input vector<int> 'dest'
template <typename IterType, typename Predicate, typename T>
void filtered_copy(IterType begin, IterType end, Predicate pred,
                   vector<T> &dest) {
```

```
for (; begin != end; ++begin) {
  if (pred (*begin)) {
    dest.push_back (*begin);
  }
}
```

```
}
```

4c) (5 points) Complete the definition of the `IsPowerOfBase` functor below, which when created with a fixed integer base, can determine whether an input integer is a power of that base (using a positive integer exponent). For example, here the functor is defined with base 2:

```
IsPowerOfBase pow_of_2(2);
pow_of_2(8); // returns true since 8 is a power of 2 (2^3 = 8)
pow_of_2(5); // returns false since 5 is not a power of 2
```

You **MUST** use this helper function:

```
// REQUIRES: num > 0, base > 0
// EFFECTS: Returns true if 'num' is a power of 'base'
//          (num = base^exp for some integer exp > 0)
// EXAMPLE: is_power_of(16, 4) is true,
//          is_power_of(9, 2) is false
bool is_power_of(int num, int base);
```

You do not have to do any error checking in your code below.

```
class IsPowerOfBase {
public:
  IsPowerOfBase( [int base_in] )
    : [base(base_in)] {}

  bool [operator()(int num)] const {
    return [is_power_of(num, base)];
  }
private:
  [int base];
};
```

```
class IntRange {
public:
  IntRange(int start_in, int stop_in);
  class Iterator {
    public:
      // Public member functions as required by 4a)
  };
  Iterator begin() const;
  Iterator end() const;
};

template <typename IterType, typename Predicate, typename T>
void filtered_copy(IterType begin, IterType end, Predicate pred,
                   vector<T> &dest);
```

Public interfaces from 4a) and 4b)

4d) (4 points) In the box below, use the `filtered_copy` function to fill the `powers_of_three` vector with all the positive integers less than 1000 that are a power of 3. Your solution must **only use** `IntRange`, `IsPowerOfBase`, and `filtered_copy`. You may **NOT** use loops or recursion. You may assume that the member functions of `IntRange::Iterator` required by 4a) are implemented.

```
vector<int> powers_of_three;
```

```
IntRange range(1, 1000);
filtered_copy(range.begin(), range.end(),
              IsPowerOfBase(3), powers_of_three);
```

```
// Now powers_of_three will have { 3, 9, 27, 81, 243, 729 }
```

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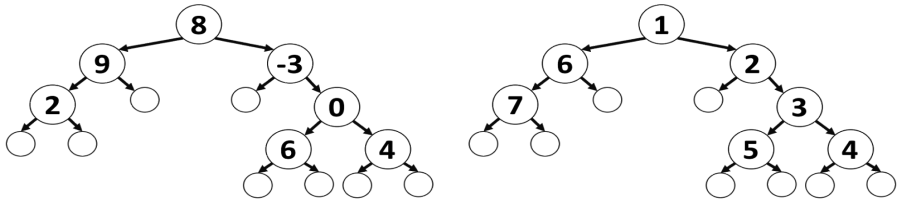
Problem 5: Recursion (14 Points)

For this question, work directly with the node struct to the right, representing a tree containing ints. You may **NOT** use any functions except those defined in this problem. Your functions **MUST** be recursive, and you may **NOT** use loops.

```
struct Node {
  int datum;
  Node *left;
  Node *right;
};
// a null pointer
// represents
// an empty tree
```

Node struct

5a) (7 points) The call `same_structure(node1, node2)` determines whether or not `node1` and `node2` have the same structure, with the same height and nodes at the same positions in each tree. The following two trees have the same structure:



Implement `same_structure()` below.

```
// EFFECTS: Returns true if the nodes in 'node1' have the same
//          structure as those in 'node2'.
bool same_structure(const Node *node1, const Node *node2) {
```

```
if (node1 and node2) {
  return same_structure(node1->left,
                        node2->left) and
         same_structure(node1->right,
                        node2->right);
}
return node1 == node2;
```

```
}
```

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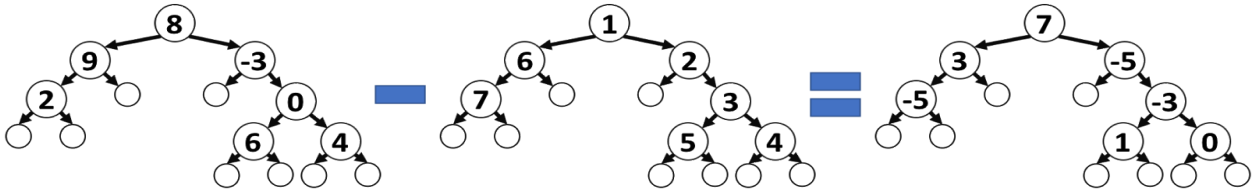
5b) (7 points) Implement the `combine()` function template below. (You do not have to assert the REQUIRES clause.) Given two trees and a function object `func` that takes two ints and returns an int, `combine()` constructs a new tree that is the result of applying `func` to each pair of elements that are at the same position in the two original trees. For example, if `node1` is the tree on the left, `node2` is the middle tree, and `func` is a function object that subtracts two ints, then the result of `combine(node1, node2, func)` is the tree on the right:




```
// REQUIRES: same_structure(node1, node2)
// EFFECTS: Returns a node structure that has the same structure as
//          'node1' and 'node2', where the element at each position
//          is the result of applying 'func' to the elements at that
//          position in 'node1' and 'node2'.
template <typename Combiner>
Node * combine(const Node *node1, const Node *node2, Combiner func) {
```

```
if (not node1) {
  return nullptr;
}

return new Node {
  func(node1->datum, node2->datum),
  combine (node1->left, node2->left, func),
  combine (node1->right, node2->right, func)
};
```

```
}
```